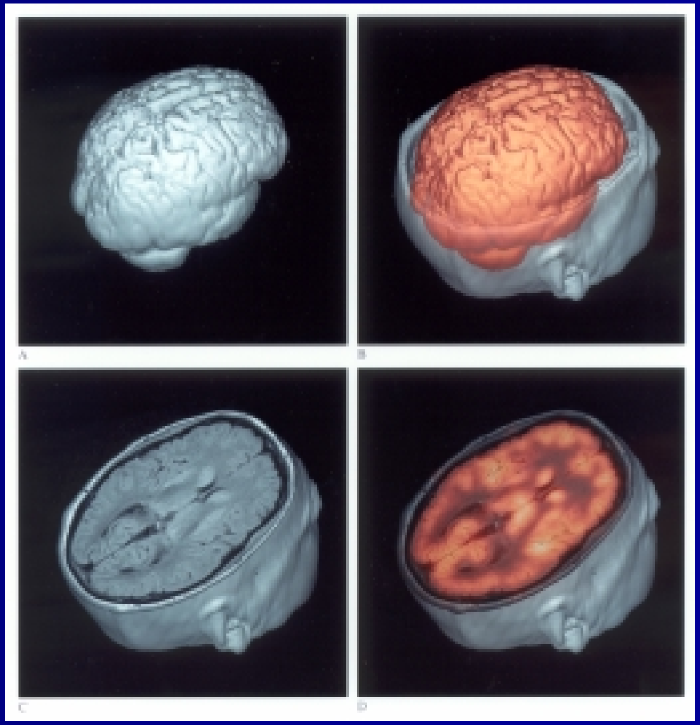
Visualization in Medical Imaging



Why visualize?

"...the ability to visualize complex data ... is essential in provoking insights, enabling communication of those insights to colleagues, and confirming the integrity of observations."

Kaufman, 1994

What’s a good visualization?

A visualization should not:

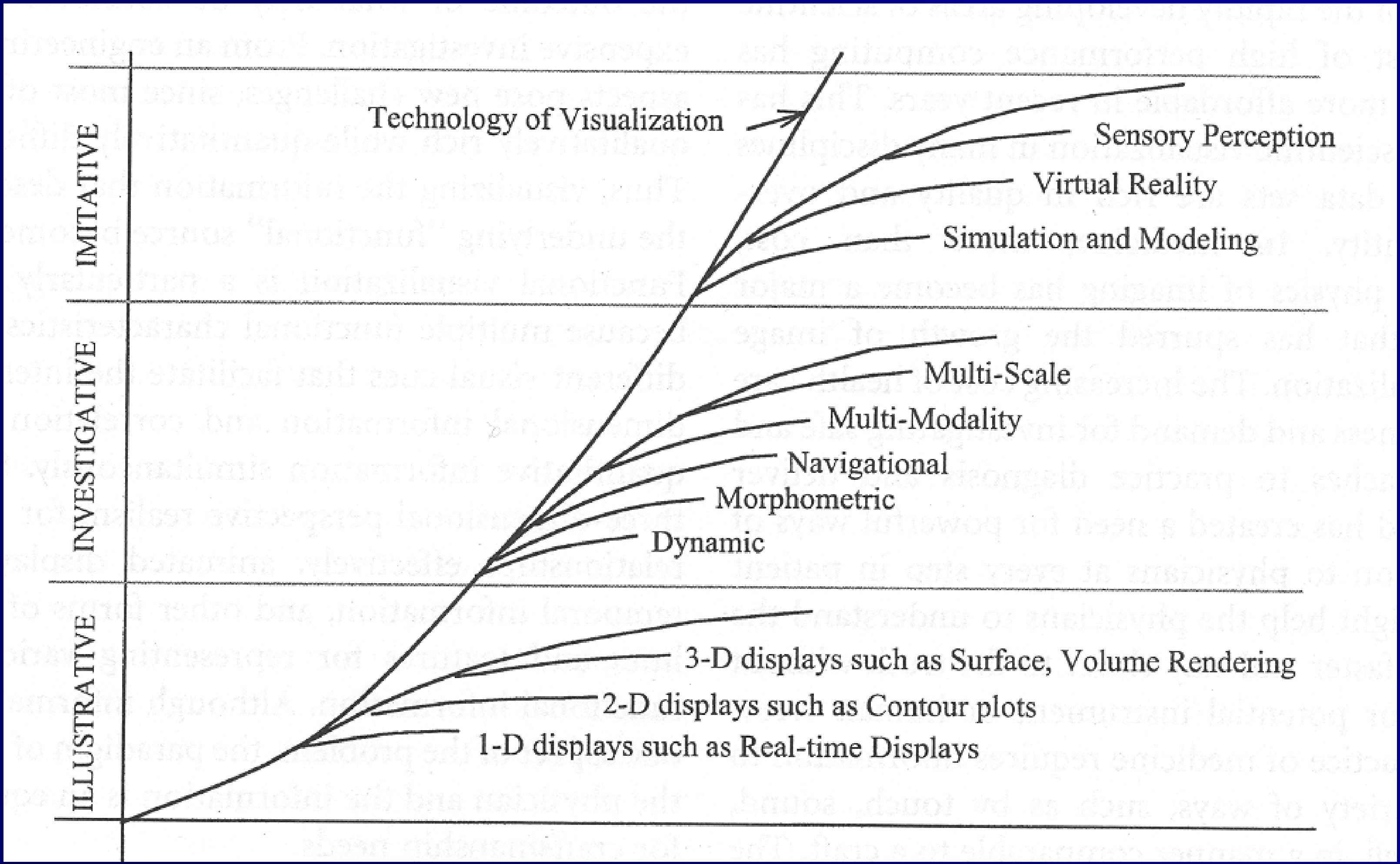
- present the wrong data
- present the right data in a misleading way
- put a heavy cognitive burden on users

A visualization should:

- be reproducible for the same dataset
- behave comparably for different datasets
- improve performance on tasks in specific applications

If we can figure out how to measure improvement!

Classes of visualization



Illustrative visualization

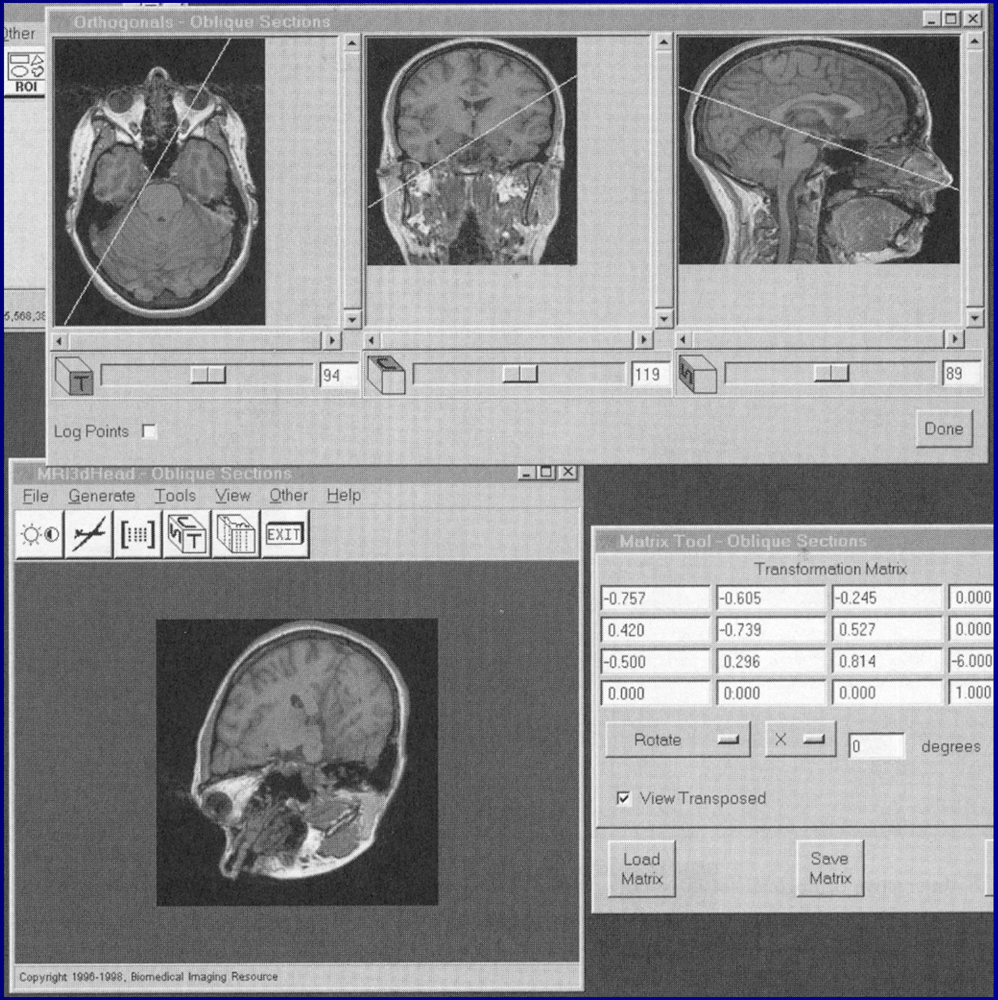
Often distinguishes extraction of information and its presentation. Accuracy and quality are more important than speed – low interactivity is ok.

- 2D displays
  - slices, contour plots
  - image enhancement, feature extraction
- 3D displays
  - surface renderings
  - volume renderings
  - shell renderings
  - deformable surfaces

Illustrative visualization

Arbitrarily oriented 2D planar slice constructed from 3D data volume.

Requires accurate interpolation, especially of non-isotropic voxels.

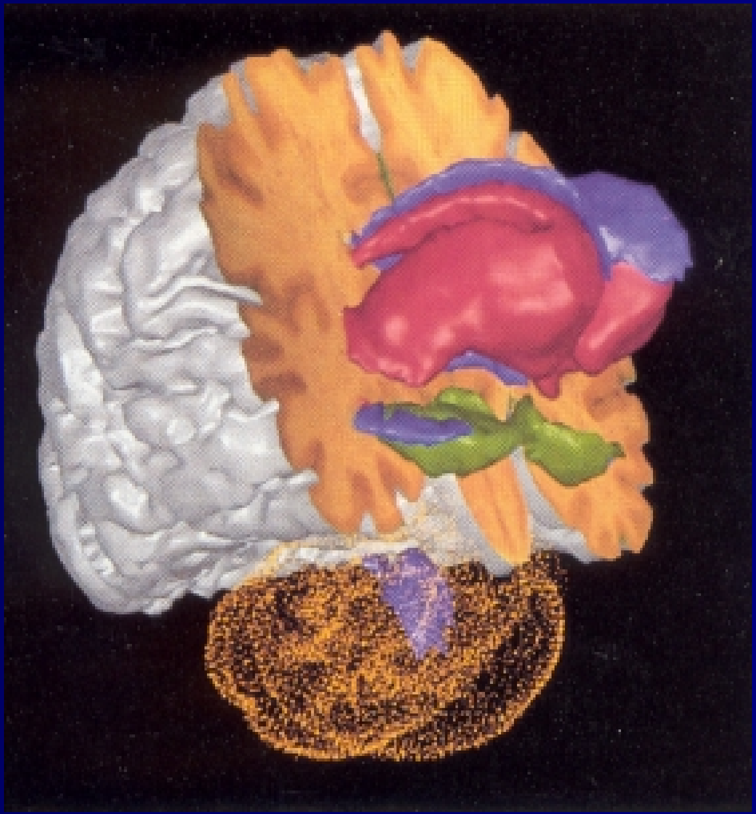


Illustrative visualization

2D curved "slice" reconstructed from 3D data volume.

Illustrative visualization

Segmented 3D volume: shaded surface renderings, 3D plotted points, texture mapping of volume data onto cut plane.



Data is from reconstructed histology of a single specimen.

Ventricles: blue

Basal ganglia: red

Cerebellum: yellow dots

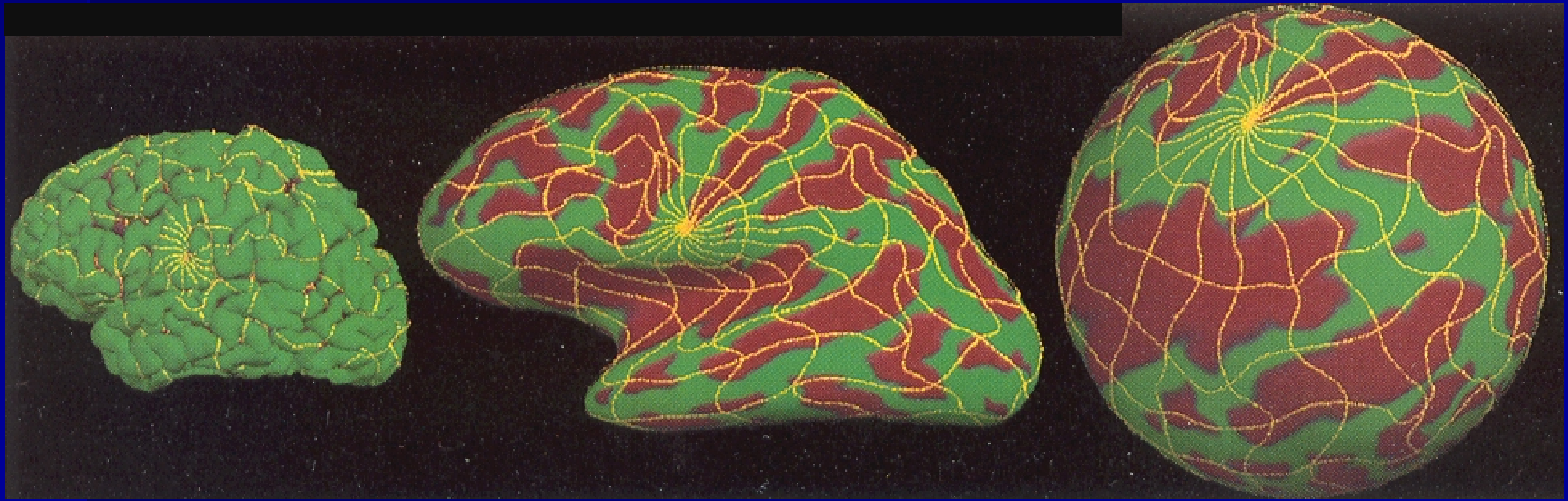
Slice shading: histological data

Illustrative visualization

Digital anatomic atlas of the head (Univ. of Hamburg) with segmentation and object descriptions. Named objects can be added or removed from display.

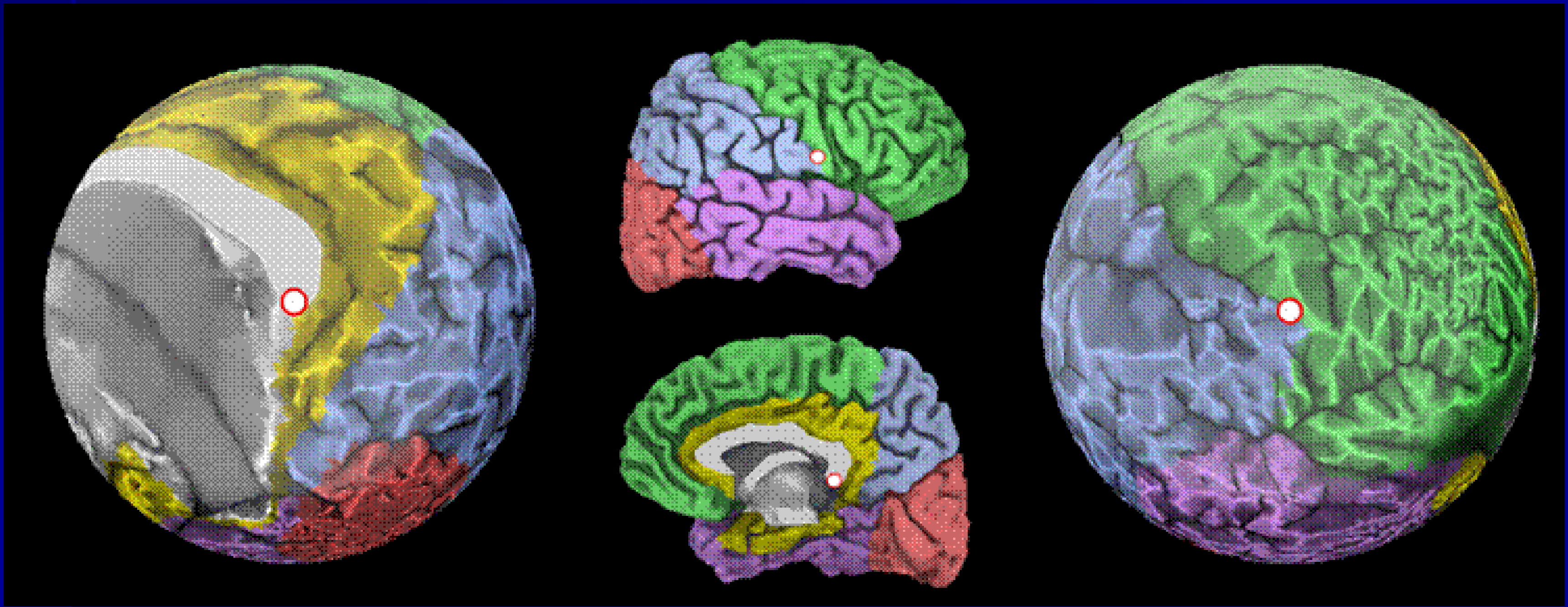
Illustrative visualization

Surfaces satisfying certain constraints can be transformed to other geometric shapes. For the human cortex, about 60% is "buried" in sulci. The method shown attempts to minimize distance and local area distortions during inflation.



Illustrative visualization

This method, conformal mapping, preserves angles, but not area or distance. In some sense, “shape” is preserved by this type of mapping.



Investigative visualization

Focuses on explorative aspects and attempts to provide visual solutions that the eye many be able to use better; speed and interactivity are vital.

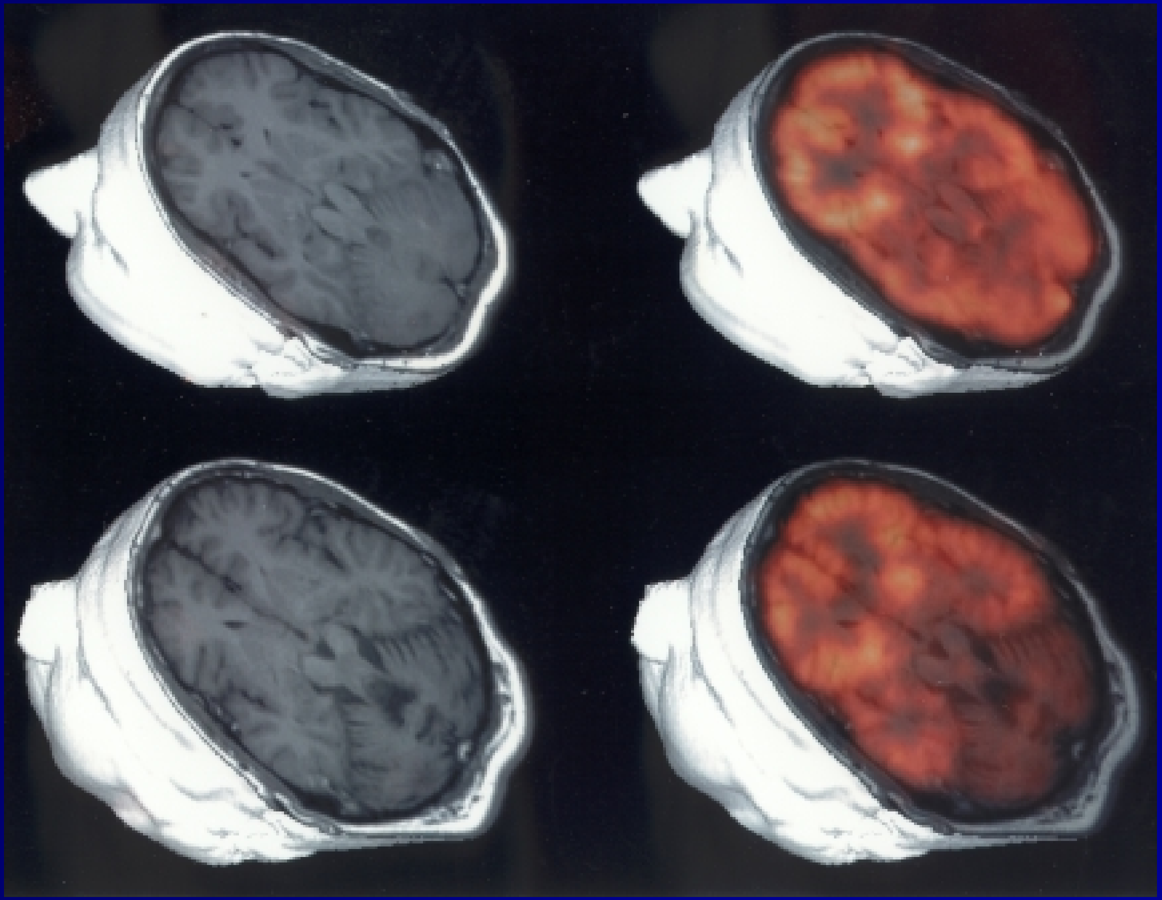
- 2D displays
  - Dynamic visualization (e.g. cine of beating heart)
  - Multimodality fusion
- 3D displays
  - Stereoscopic visualization
  - Volume morphing
  - Navigational visualization
  - Flow visualization

Multimodality visualization

Normal and cerebellar ataxia subject, merged MRI and FDG scan

Note structural atrophy and reduced activity in the cerebellum

FDG : fluorodeoxyglucose



Virtual endoscopy

Virtual endoscopies are classed as “navigational” visualizations – used to travel through internal structures.

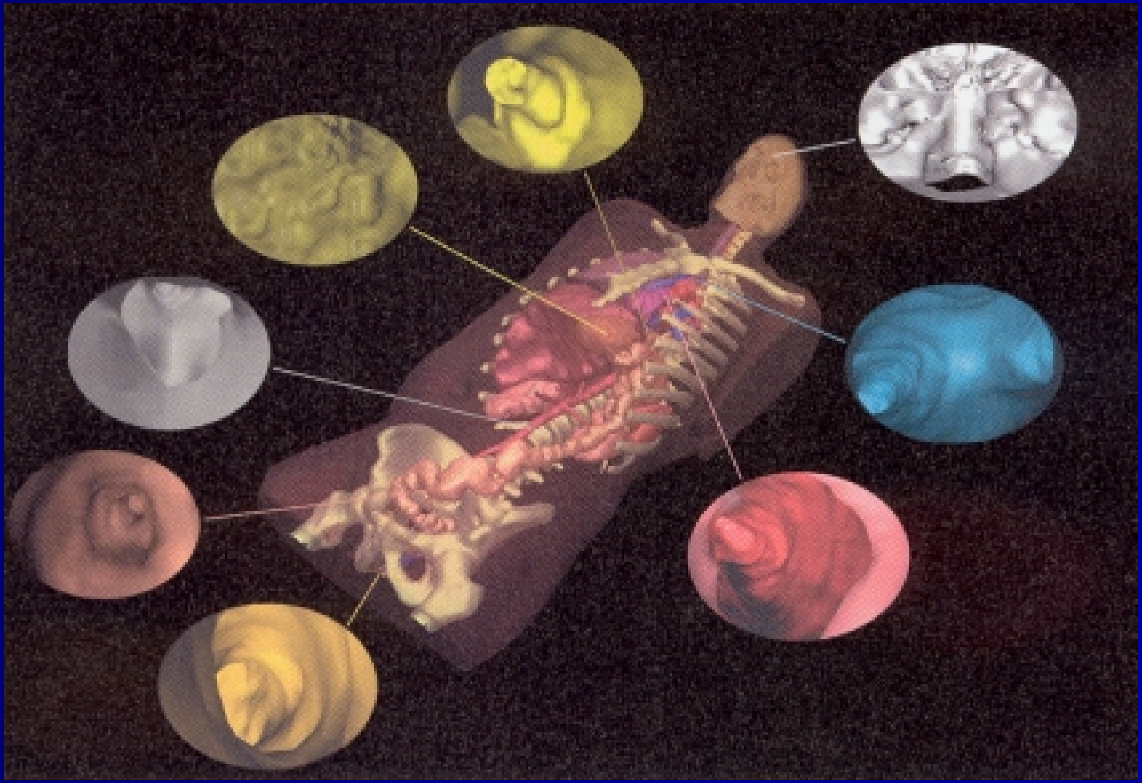
Advantages:

- less invasive than physical probe
- ability to maintain spatial orientation in body
- can visualize external as well as internal structures
- potential for CAD support

Virtual endoscopy

Top right, clockwise
- skull, looking down spine
- inside trachea
- inside heart
- within ureter
- within colon
- in spinal column
- in stomach
- in esophagus

Visible Human Male

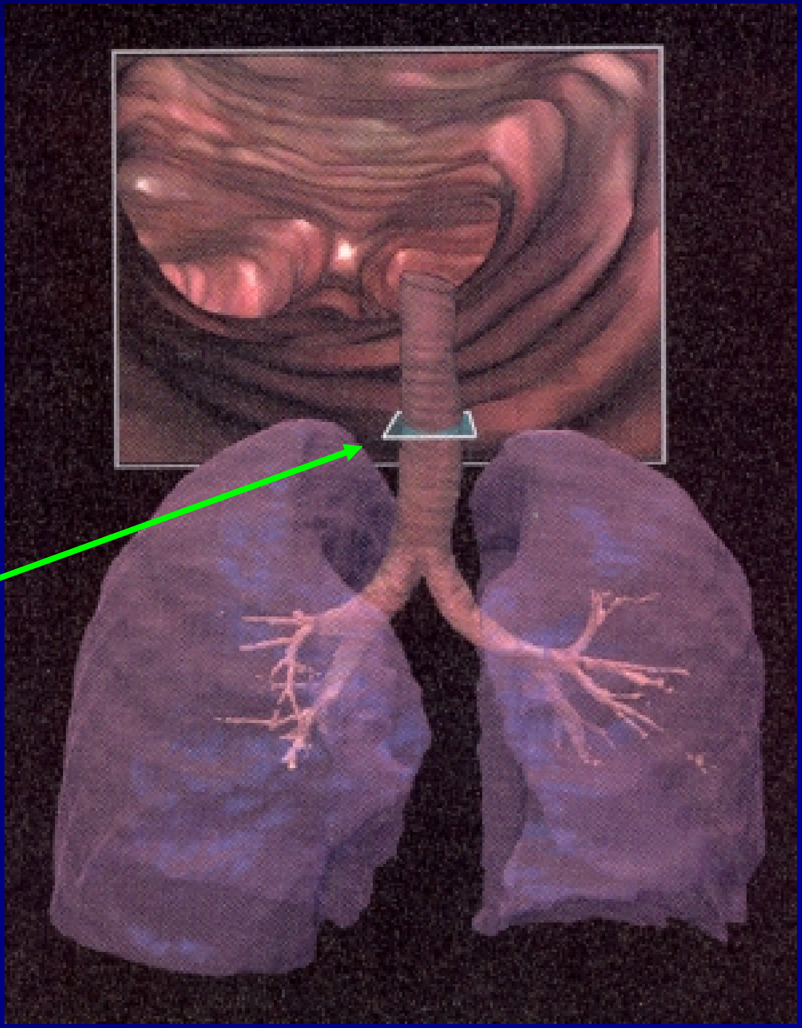


Virtual endoscopy

Segmented and texture mapped volume models of lungs and trachea with interior endoscopic view.

Navigation frame shows view location.

Visible Human Female



Imitative visualization

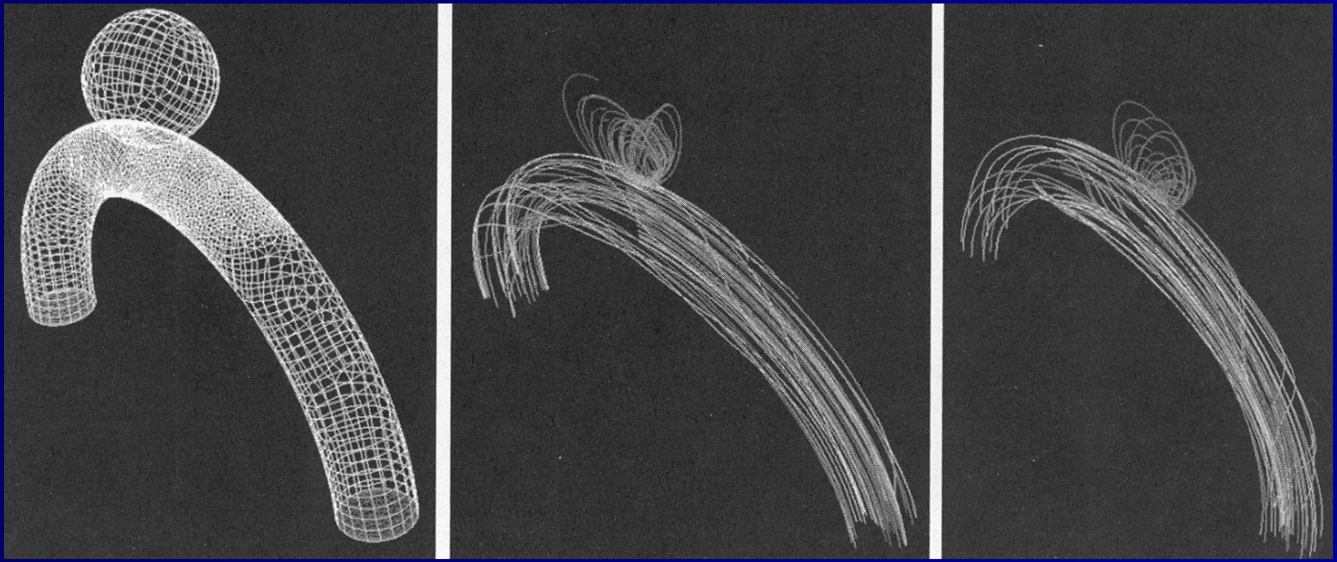
Attempts to imitate visual perception (virtual reality) or function (simulation and modeling).

- Modeling blood flow
- Virtual reality
  - immersive
  - virtual workbench
- Augmented reality
  - intraoperative image fusion with real world objects

Imitative visualization

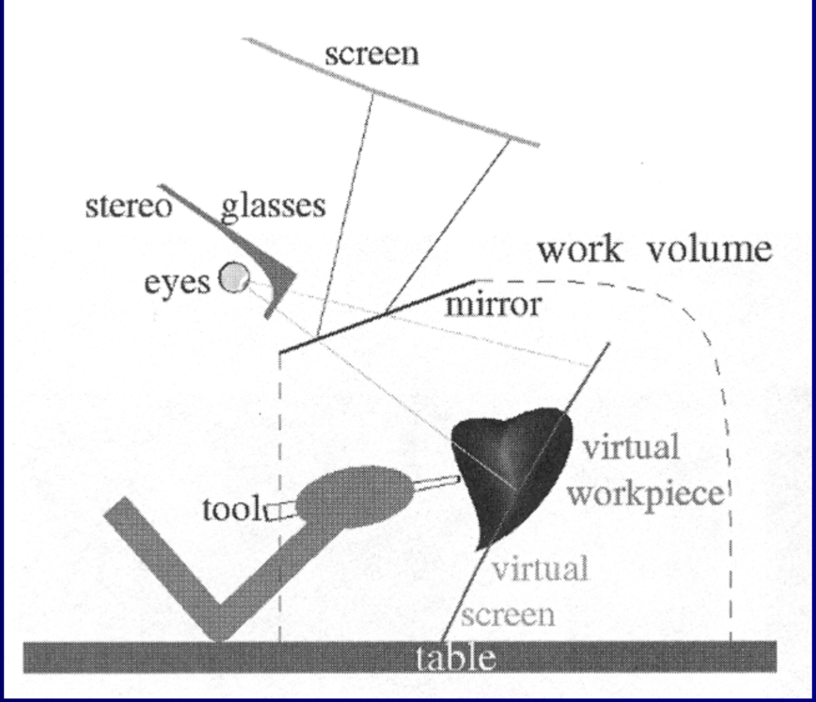
Modeling blood flow through an aneurysm and its visualization

Left: synthetic model. Middle: blood flow in absence of coils in aneurysm. Right: After simulation of coil placement to reduce blood flow, and thus potential to rupture.



Imitative visualization

Virtual workbench – presents a fully synthetic world



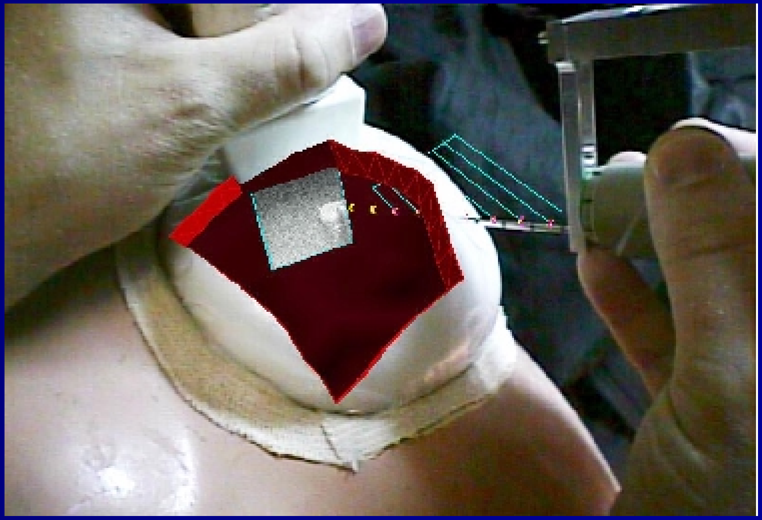
Viewer perceives 3D objects as behind the mirror, apparently where he or she can reach in to touch it with a tool.

The stylus or mouse can be replaced in the visualization by the appropriate tool model.

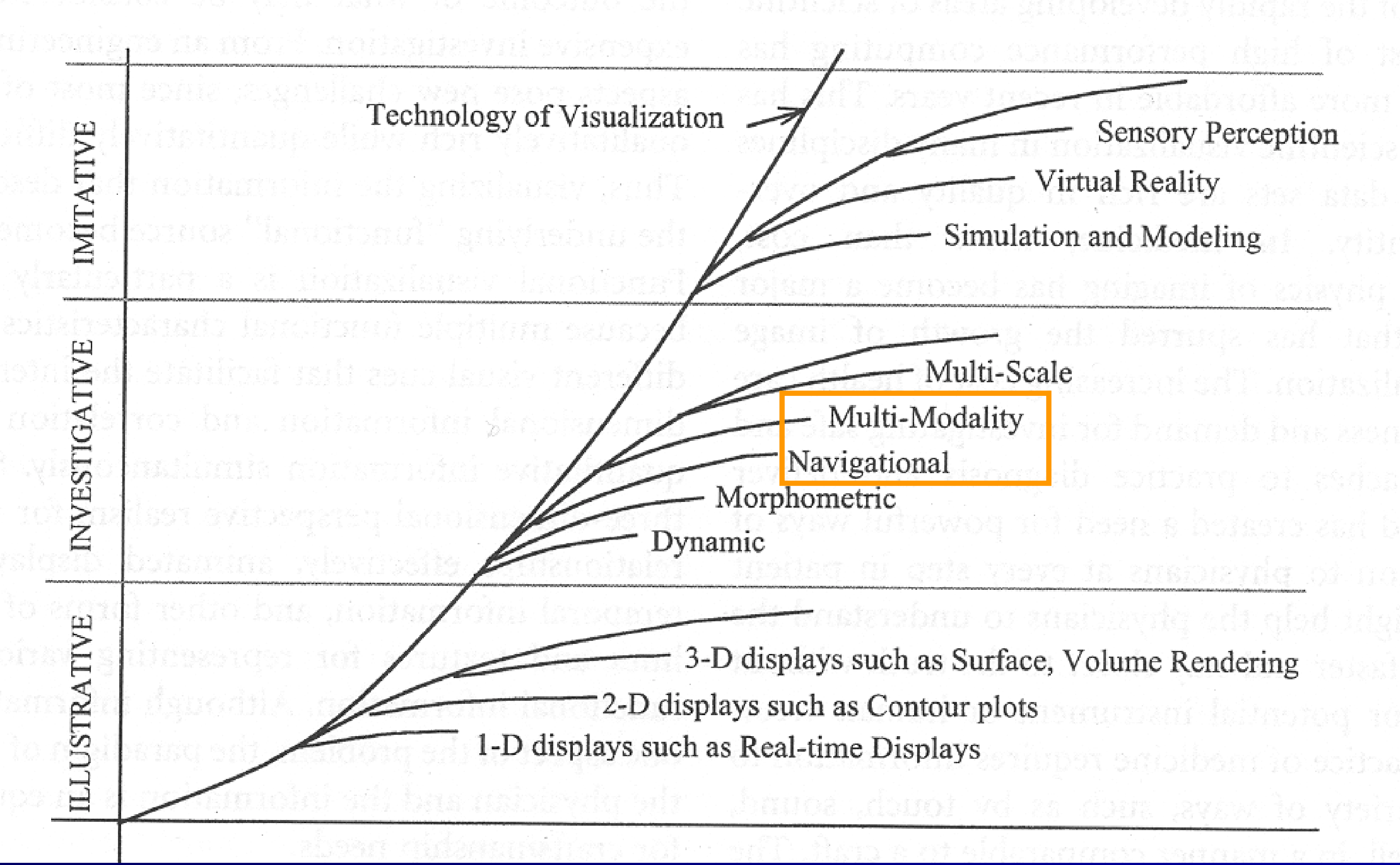
Imitative visualization

Augmented reality – needle biopsy of breast phantom

Video see-through system with 2 video cameras and LEDs for tracking the head-mounted display. Red area depicts augmented reality field of view. Left hand holds ultrasound probe – image square shows US image with lesion as a bright spot. Right hand holds needle – trajectory to lesion is shown.



Classes of visualization



Multimodality visualization

We acquire and visualize image data from different modalities to extract and combine different types of information.

Combination means working with image volumes that are spatially co-registered, and possibly placed in a standard orientation and coordinate system.

Color encoding methods are widely used for image combination or “fusion”.

Multimodality visualization

Three common methods (color-channel encoding, hue-luminance encoding, and composite color) may require quantization of intensity levels into a limited range for each image (e.g. 32 & 8 or 16 & 16). Color interactions between MRI and PET scales can make it difficult to recognize areas with equivalent functional data values.

“Screen-door” fusion allocates 1/2 the available colors to each image. Images are colored independently, which allows the use of familiar color scales.

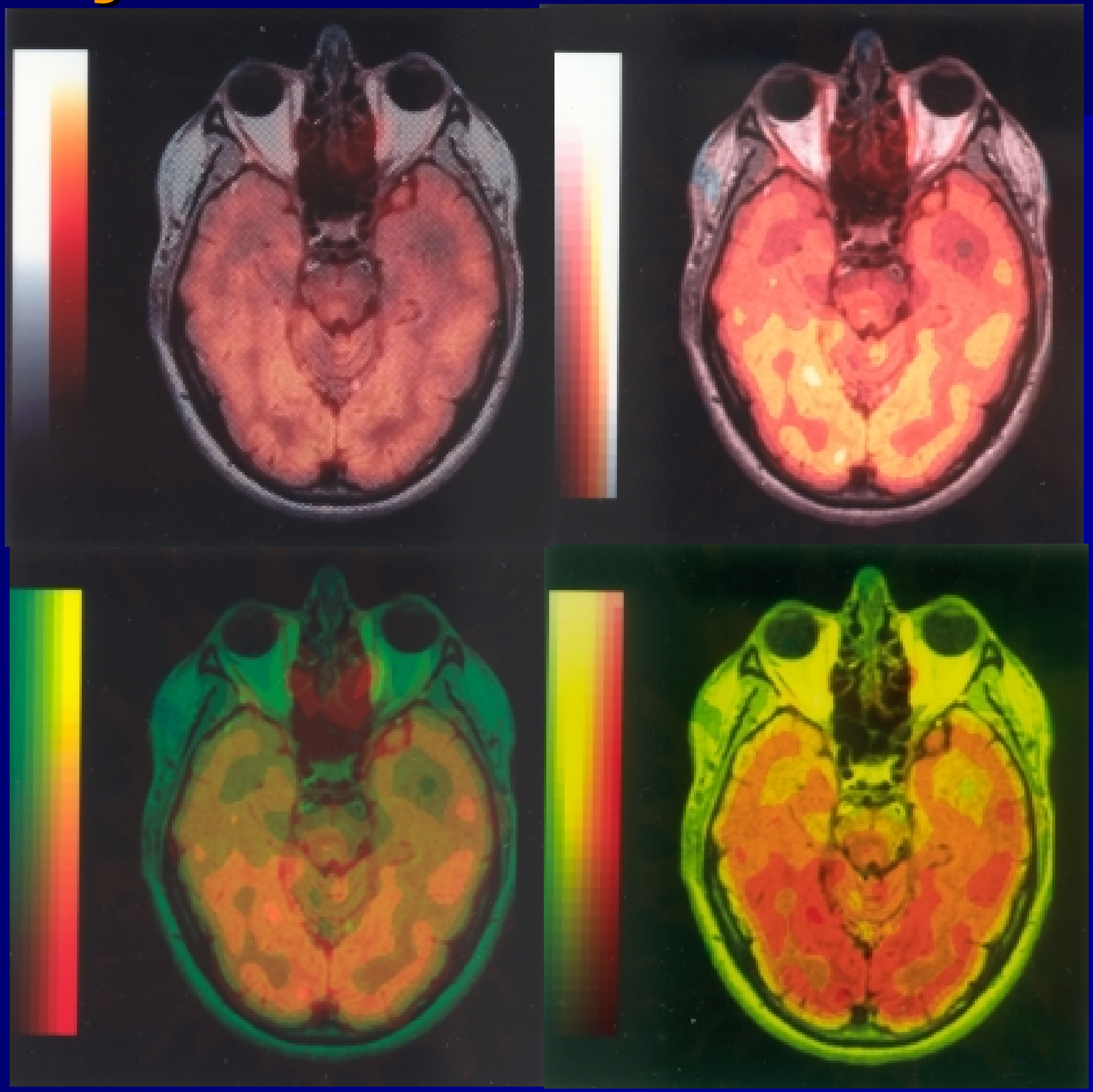
Multimodality visualization

Screen-door fusion

Composite color

Red/green encoding

Hue/luminance encoding
(MRI in luminance)



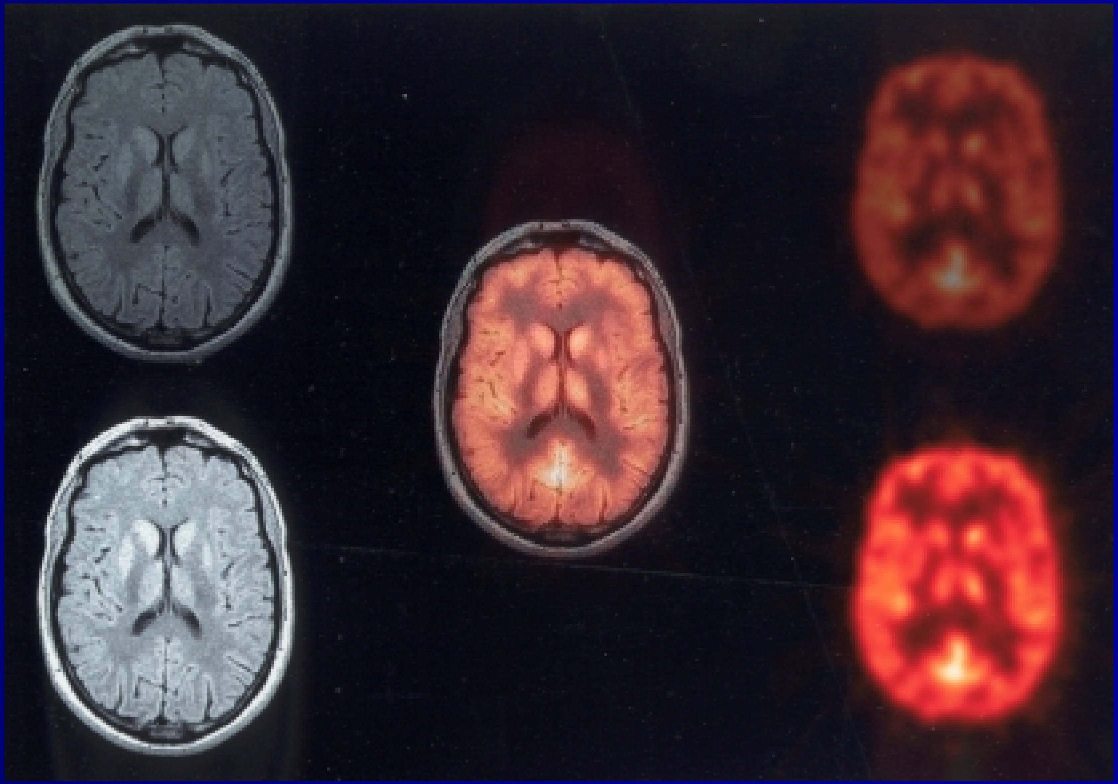
Multimodality visualization

Screen-door fusion uses a checkerboard of pixels – so why don't we see it?

The checkerboard images onto the fovea at about 14 cycles/degree.

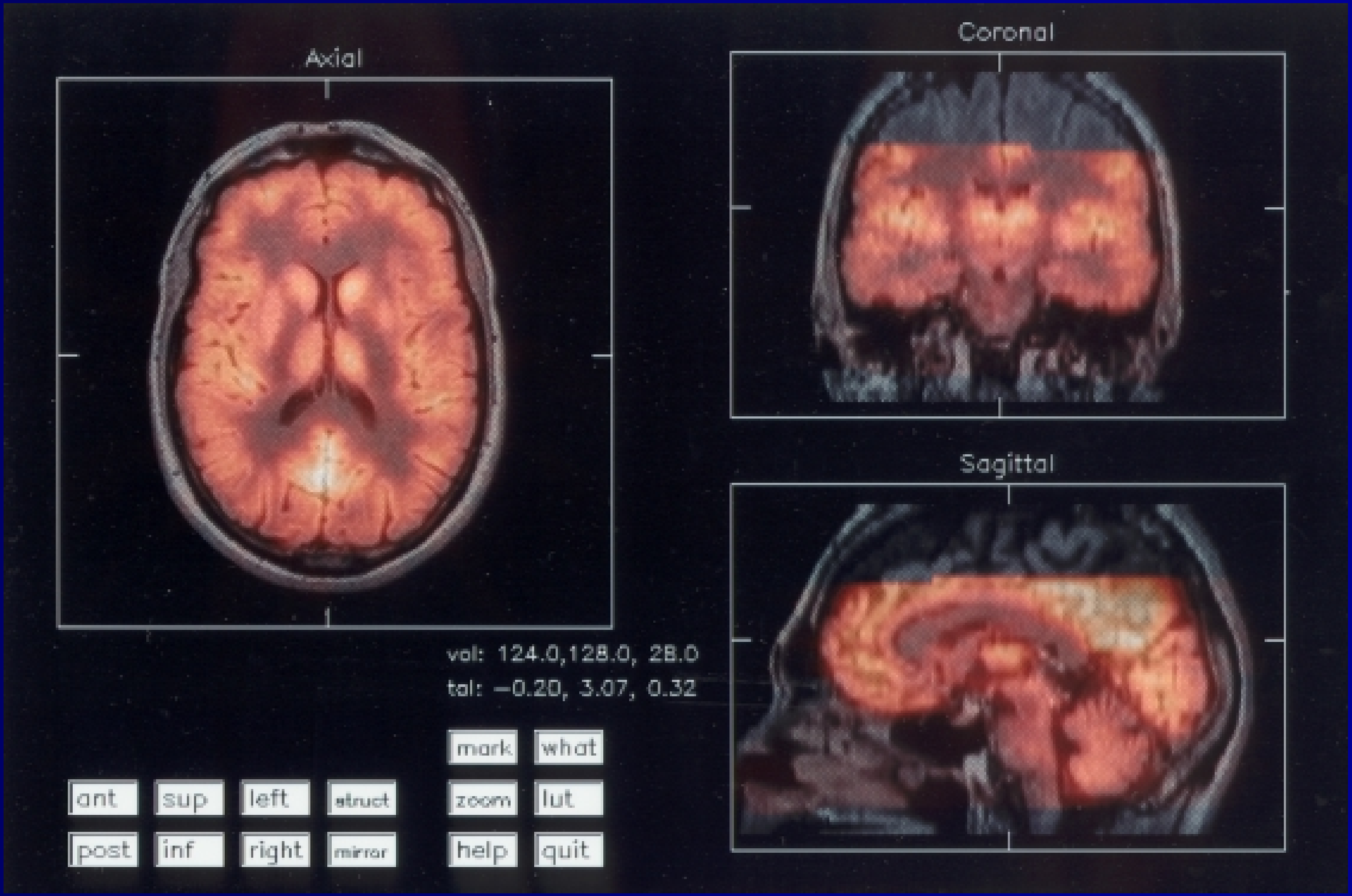
At the monitor's luminance, the eye's contrast sensitivity peaks at around 5 cycles, and falls off by a factor of 10 at 14 cycles.

The checkerboard is not perceived unless the contrast is very high!



And you thought you'd never hear about visual psychophysics again!

Multimodality visualization

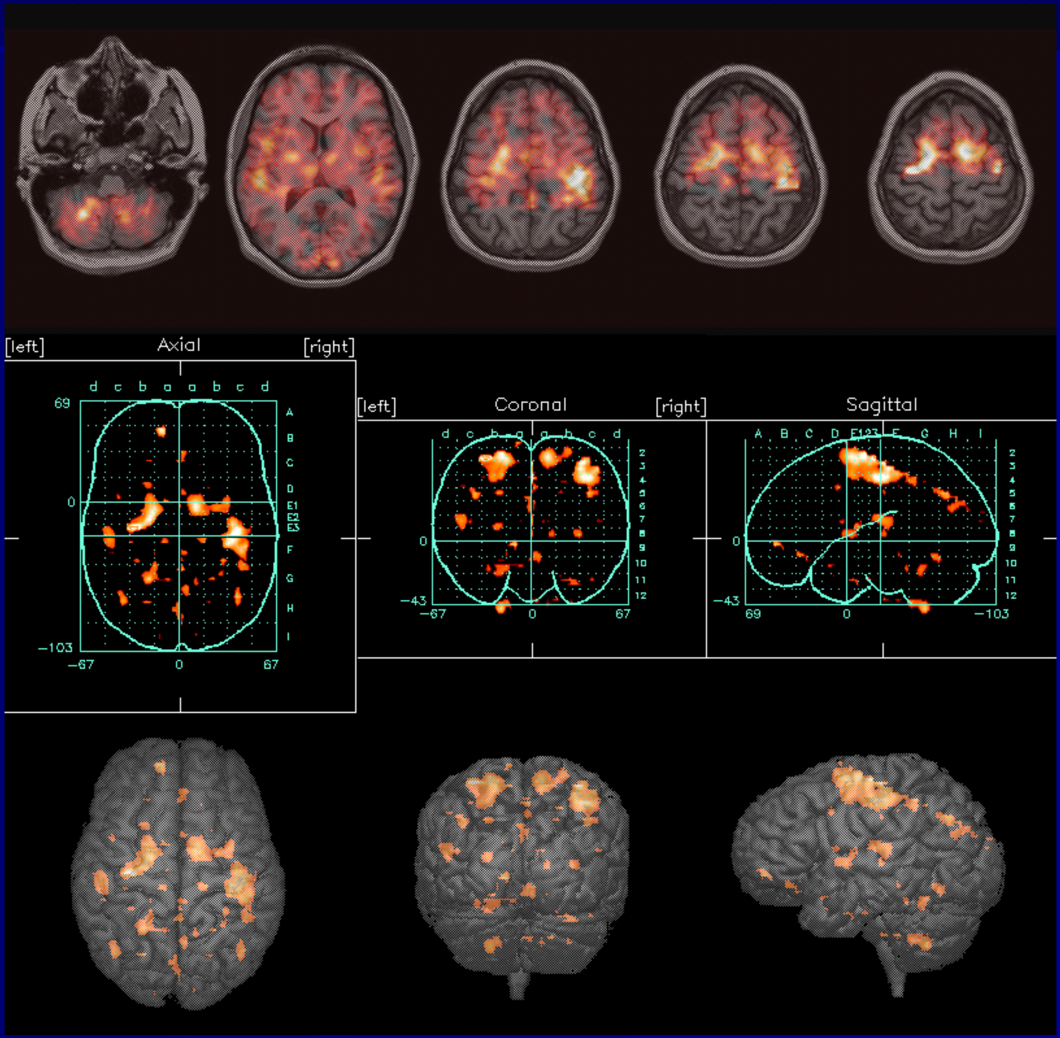


Multimodality visualization

Gallery of slices

Maximum intensity projection (MIP) onto coordinate grids.

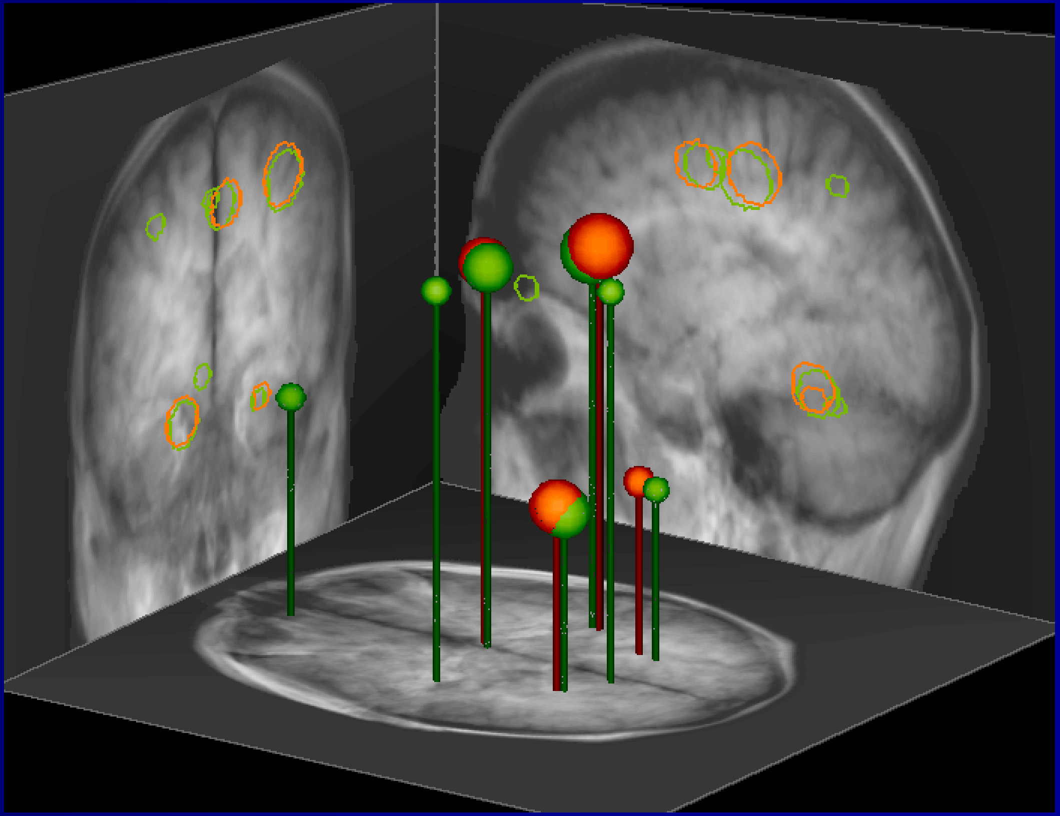
Maximum intensity projection onto surface renderings. (No opacity constraints were applied.)



Multimodality visualization

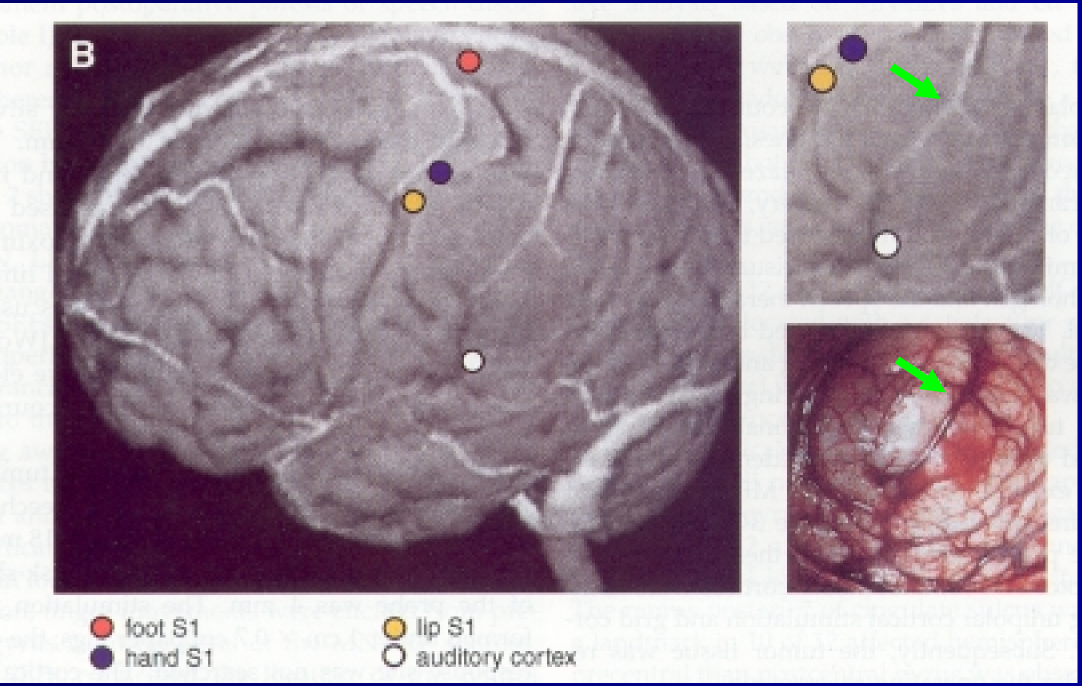
Not all visualizations require exquisite detail – sometimes the aim is to provide a quick overview of several large data volumes.

Symbolic representation can allow an observer to appreciate gross similarities and differences in data obtained from fMRI (green) and PET (orange) studies of the same functional activation protocol – left-handed sequential finger opposition.



Multimodality visualization

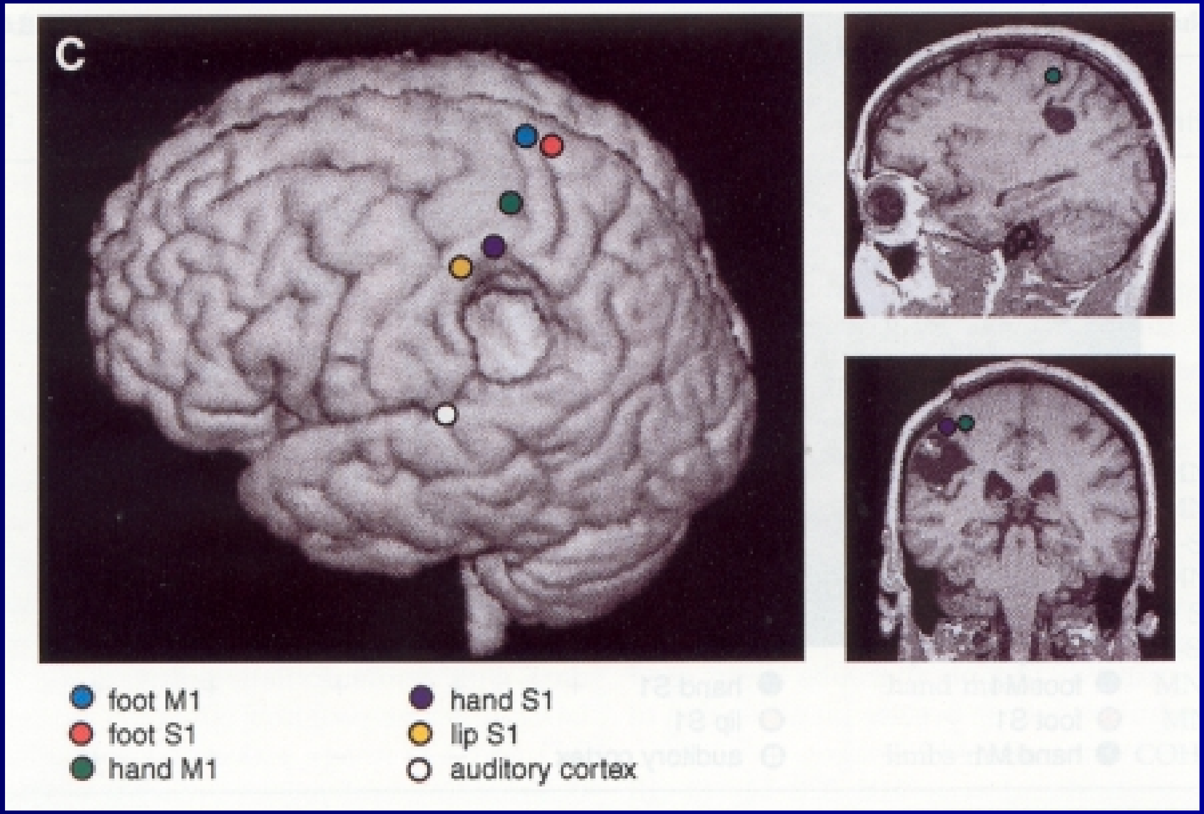
Surface rendering of T1-weighted MRI volume of patient with large brain tumor. Veins were reconstructed from a contrast-enhanced (gadolinium) MR image and superimposed onto the surface.



Markers represent locations of responses to external stimulations measured using magnetoencephalography (MEG).

3D image fusion

Surface rendering of T1-weighted MRI volume of patient after tumor resection.



Virtual endoscopy (VE)

VE is typically used to visualize small structures such as airways, blood vessels and colonic polyps that may be 1cm or less in size.

High resolution (desirably 1mm^3) voxels are required to generate a VE. Usual imaging modalities will be spiral CT or MRI.

Usual viewing is as static images or as a "fly-through" that simulates conventional endoscopy.

Virtual endoscopy (VE)

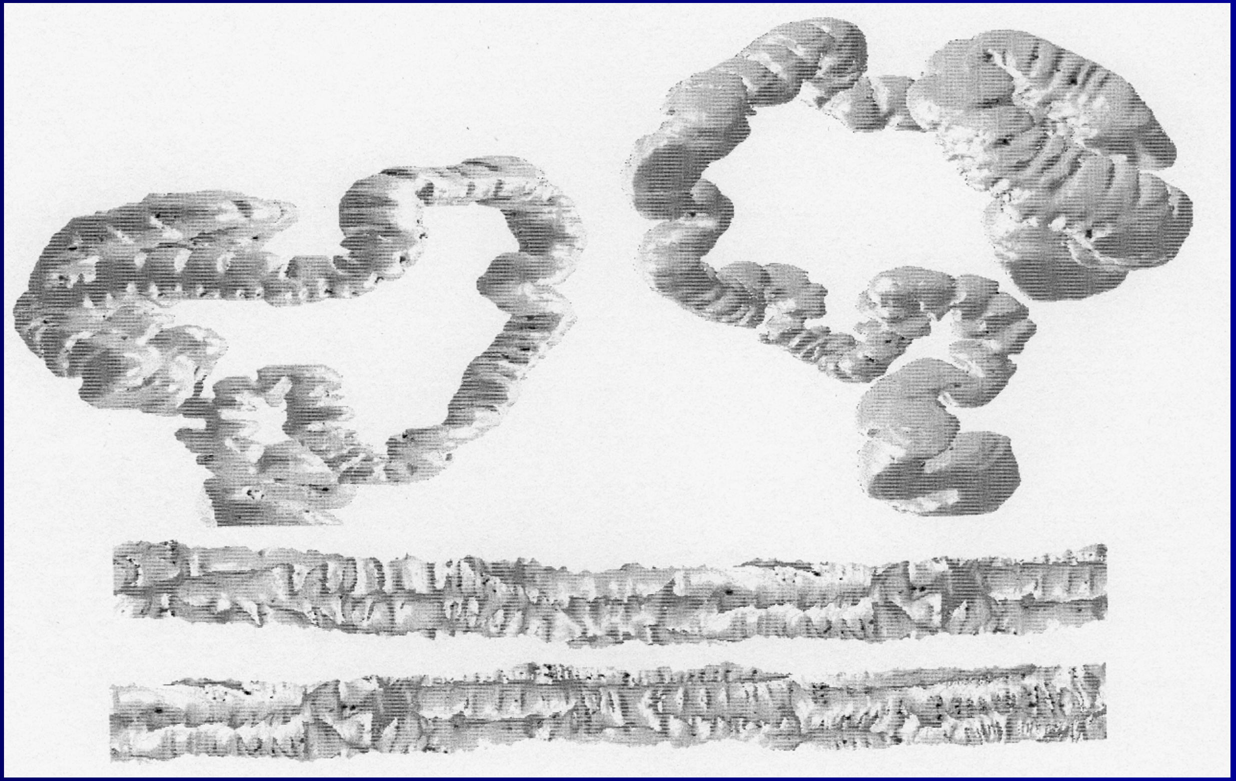
Important tasks are to detect lesions and determine their significance.

Current problems:

- interpretation can be inefficient and tedious
- in colon, lesions can be missed if they lie behind folds
- in colon, retained feces can simulate masses (lacking visual cues of conventional endoscopy)
- diffuse problems like inflammation are not detectable

Virtual endoscopy (VE)

Polyps hidden behind folds – one approach under investigation is that of "flattening" the intestine.



Virtual endoscopy (VE)

CAD systems can find and mark likely endoluminal lesions (those that distort the wall of a hollow structure) using measures of local curvature.

Local shape of an isosurface at any point can be described by the Gaussian and mean curvatures – which in turn determine measures of principal curvature.

R. M. Summers, *Morphometric Methods for Virtual Endoscopy.* In: Handbook of Medical Imaging, I. Bankman, ed. 2000.

Virtual endoscopy (VE)

Gaussian (H) and mean curvatures (K) define the minimum and maximum principal curvatures at a point.

$$\kappa_{\text{max}} = H + \sqrt{H^2 - K}$$

$$\kappa_{\text{min}} = H - \sqrt{H^2 - K}.$$

They can be thought of as 1/radii of the smallest and largest circles that can be laid on the surface tangent to a point P. The greater the curvature, the smaller the circle.

Virtual endoscopy (VE)

Principal curvatures can be used to classify the type of a vertex.

- "peak" type with elliptical curvature is suggestive of a lesion
- cylindrical curvature is typical for normal airway and colon
- hyperbolic curvature describes saddle points at bifurcations and cartilaginous rings
- "pit" type with elliptical curvature suggests ulcerations

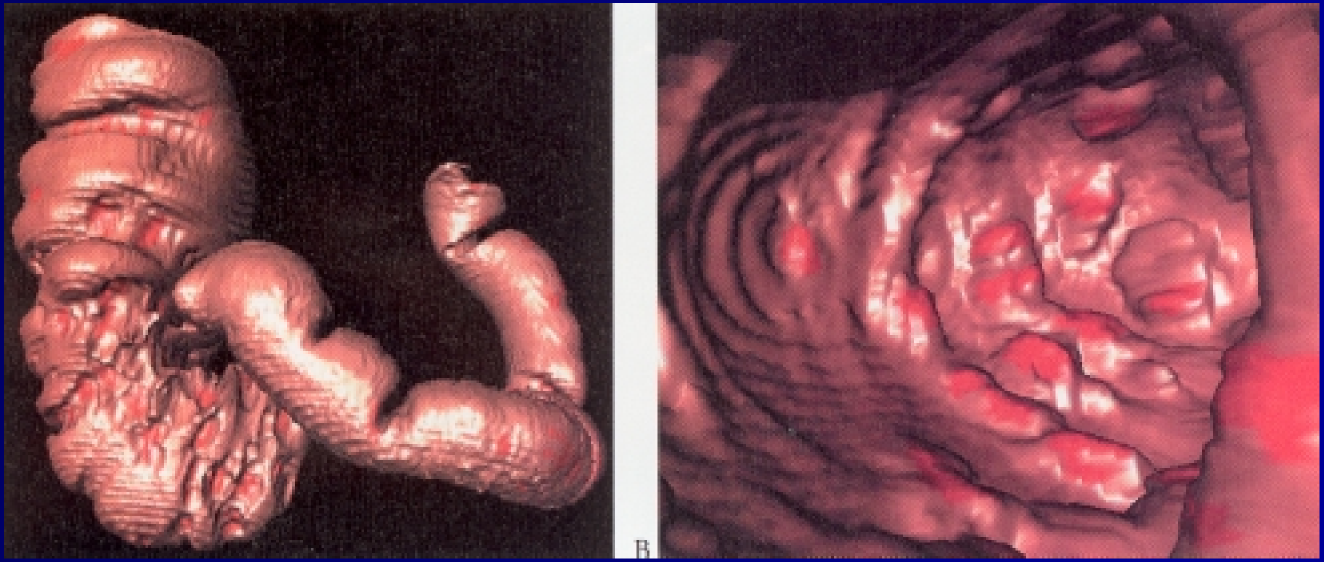
Virtual endoscopy (VE)

Vertices of the selected type are clustered together by region growing to determine if they meet a minimum size criterion.

In a study of 18 virtual bronchoscopy patient examinations, authors report sensitivities of 55 to 100% and specificities of 63 to 82% depending on choice of an adjustable parameter.

Virtual endoscopy (VE)

CAD lesion detection in human autopsy specimen. Nodule areas shown in red correspond with pathologically proven disease.



Virtual endoscopy (VE)

- Another endoluminal surface abnormality potentially detectable with VE is surface roughness, though what constitutes “normal” roughness is not well known.
- Speculation is that texture that is too smooth may result from inflammation and edema, and texture that is too rough may indicate a tumor.
- Fractal dimension is proposed as a measure of surface roughness.

Virtual endoscopy (VE)

The authors investigated using a modified version of the Minkowski sausage to measure fractal dimension. Here, this involves computing the volume swept out as spheres of varying diameter are passed along the rough surface.

They found that the method (though it did not correspond exactly to imposed fractal dimensions of test objects) provided the correct roughness ranking.

Fractal dimension measurements are very sensitive to noise and spatial resolution of data, and are yet to be stable features for computer-aided diagnosis.

Virtual endoscopy (VE)

M indicates mass adjacent to bronchus wall.

Mass side of wall is irregular

FD = 2.38 +/- 0.05

* indicates smooth wall

FD = 2.26 +/- 0.04